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Evaluation of Temperature Changes in the Pulp Chamber During Polymerization of Pulp Capping Materials

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Abstract

Objectives: Polymerization of resin-based materials leads to temperature rise, caused by the exothermic nature of the reaction and energy absorbed during polymerization. This temperature rise is influenced by intensity of light, composition of resins, and type of light source. This study evaluated thermal insulating properties of four photo-polymerizing pulp-capping agents in primary and permanent teeth.

Methods: Roots of 80 primary and permanent teeth were removed. Class-I cavities were prepared on the occlusal surfaces of teeth. Materials used were TheraCal LC, Biner LC, ACTIVA BioACTIVE, and Calciplus LC and light sources were 3M-Elipar and VALO LED. Temperature rise was measured using a J-type thermocouple. Data were statistically evaluated using ANOVA and Tukey`s tests ($p=0.05$).

Results: VALO LED exhibited significantly lower temperature rise in all groups and temperature rise in primary teeth was significantly higher with all experimental materials ($p<0.05$). The highest temperature change was observed in the Biner LC group (3.82±0.58) and the lowest change in the Activa-BioACTIVE group (1.78±0.34).

Conclusions: The VALO LED light source caused a significantly lower increase in pulpal temperature compared with the 3M-Elipar source. All tested materials and light sources maintained pulpal temperature under safe limits, with temperature increases not exceeding 5.5 ºC.

Keywords: Dental cavity liner, dental curing lights, pulp capping, primary teeth, temperature.

Running Head: Thermal effect of capping materials

Introduction

One of the major objectives of restorative treatments is maintenance of pulp health. Pulp is a highly vascularized tissue and pulpal temperature must not exceed normal values during restorative procedures. Pulpal temperature can be affected by various procedural factors such as cavity preparation, exothermic polymerization, acid-base setting reactions of restorative materials, or tooth exposure to light from various light sources [e.g., quartz-tungsten-halogen (QTH) and light emitting diode (LED)] used for curing restorative materials [1-3]. Zach and Cohen reported that pulpal temperature rise above 5.5 ºC caused significant histological changes in pulp tissues (including protoplasm coagulation, expansion of liquid present in dentinal tubules, vascular injuries) and necrosis of dental pulp [4].

Especially in deep cavities, remaining dentin thickness is one of the most important factors affecting health of the pulp. An inverse relationship exists between dentine thickness and pulp temperature [5]. When dentin thickness decreases, probability of pulp tissue being affected by bacterial toxins and thermal changes increases. In these cases, pulp-capping materials can be used for protection of the dentin-pulp complex against thermal stimuli, bacterial penetration, chemical irritants from restorative materials, and for their antibacterial activity during operative procedures [6,7]. Calcium hydroxide is the most widely used pulp-capping agent. Its advantages include alkaline pH, antibacterial effect, and induction of new dentin formation. However, its major disadvantage is high solubility, multiple tunnel defects in reparative dentine, weak strength of bonding to dental hard tissues, and bacterial invasion [8].

To address these problems, light-curing pulp-capping materials were developed. These contain polymerizable methacrylate monomers with adequate shear strength of bonding to resin-based dental materials. Their advantages include low solubility, short setting time, comfortable application, induction of odontoblastic differentiation, and mineralization effect [9,10]. Despite all these advantages, heat generated during polymerization of these materials could lead to irreversible pulpal damage [11]. Both exothermic polymerization of the material and energy absorbed from the light-curing unit (LCU) are responsible for increase in pulpal temperature. Various studies have shown that use of LCUs causes temperature rise in the pulp chamber [2,5,12,13]. LED technology has become available as an alternative energy source to conventional LCUs. LEDs have several advantages over conventional LCUs including coincidence of peak irradiance of LED light with camphoroquinone, reduced curing time, lamp duration time of approximately 10,000 hours, lesser heat generation, rechargeable batteries, light weights, and ergonomic designs [14]. VALO is a new generation LED curing unit with an extra power mode (4,500 mW/cm2). The advantage of the VALO LED curing unit over the LED curing unit is that it allows short term (3-second) polymerization of resin-based materials [15].

The aim of this study was to evaluate temperature changes in the pulp chamber during polymerization of four different light-curing pulp-capping materials using two different LED LCUs, and functional properties gained by the materials due to the temperature changes.

Methods

The present study was approved by the Ethical Board of Necmettin Erbakan University, Konya, Turkey, under approval no. 2017/011. Eighty freshly extracted caries-free mandibular primary and permanent molar teeth were used. The teeth were cleaned using an ultrasonic scaler and pumice slurry and stored in distilled water until used. After cleaning, the teeth were sectioned at the root portion approximately 2 mm below the cemento-enamel junction and perpendicular to the long axis using a diamond bur (KG SORENSEN, Sao Paolo, Brazil) with a high-speed rotary instrument under watercooled conditions. Class-I cavities were prepared on the occlusal surface of the teeth. Remaining dentin thickness between the occlusal cavity floor and pulp chamber was set to 1 mm using a precision caliber. Pulp remnants were removed in a retrograde manner and the teeth were attached to an apparatus to simulate pulpal blood microcirculation [Figure 1]. A standard infusion set (Gemed Medical Co., Istanbul, Turkey) with a 21-gauge (green) injector needle was attached to a distilled water reservoir (1,000 mL). The injector needle was shortened to 5 mm length, and the tip of the needle (1 mm in length) was placed on a plastic plate through an artificial perforation and used as water inflow access. Another needle tip connected to a freestanding infusion tube was placed just contiguous to the first one to be used as water outflow exit and needle tips were fixed to the base plate using flowable composite. Water flow rate of the system was set to a constant amount of 0.026 mL/min using a digital infusion flow meter (SK-600II infusion pump, SK Medical, Shenzhen, China) which was attached to the system. Water simulating pulpal blood was set to 15 cm H_2O pressure and 37 ºC. A thin layer of silicone oil-based heat transfer compound was applied to the thermocouple wire (AB 25 NN, Thermocoax, Heidelberg, Germany) which was inserted into the pulp chamber to contact the occlusal wall of each tooth to measure temperature changes. The thermocouple wire was connected to a data recorder (XR440-M Pocket Logger; Pace Scientific, Mooresville, USA) and a computer to record temperature data from inside the pulp chamber during polymerization.

Four different pulp-capping materials TheraCal LC, Biner LC, ACTIVA BioACTIVE Base/Liner, and Calciplus LC and two different LCUs VALO LED and 3M Elipar LED were evaluated for their effect on temperature: [Table 1], [Table 2].

Specimens were randomly distributed to groups as follows [Figure 2].

The pulp-capping materials were applied to the dentin surface to a thickness of 1 mm as per manufacturers' instructions and polymerized for 3 s (VALO LED) or 20 s (3M ELİPAR LED) using an LED LCU (contact position). Light output power of the LCU was measured with a radiometer before and after light exposure in each group for standardization. Sampling rate of the data logger was set to one sample every 2 s and recording duration was approximately 40 s starting with light application until a temperature decrease was noticed. For each sample, initial temperature and maximum temperature increase were measured. Data collected in both tabular and graphic forms were monitored in real time and transferred to a computer. Difference between the initial and highest temperature readings (Δt) was obtained.

Temperature change data were analyzed using the software IBM SPSS Statistics version 20.0 (SPSS, Chicago, IL, USA). The Levene test and Shapiro–Wilk test were used to test for equality of variances and the normality assumption, respectively ($p>0.05$). Analysis of variance (ANOVA) followed by Tukey's honestly significant difference test (SPSS Inc, version 15.0, Chicago, Ill., USA) were used to compare temperature changes between groups. The standard level of significance of was set at $p=0.05$.

Results

Mean values and standard deviations of temperature rises in the pulp chamber during polymerization in primary and permanent teeth in all groups are shown in [Table 3] and [Table 4]. Pulp temperature increases in the VALO LED groups were less than those in the 3M Elipar LED groups, in both primary and permanent teeth ($p<0.05$). Pulp temperature increases using VALO LED or 3M Elipar LED were statistically higher in all primary teeth groups than in all permanent teeth groups ($p<0.05$). For pulp-capping materials, the highest temperature rise and the lowest temperature rise were found in the Biner LC and the ACTIVA BioACTIVE groups, respectively, in the all LCU groups both primary and permanent teeth no significant differences were found betweeen the ACTIVA BioACTIVE and the CalciPlus LC groups ($p>0.05$), but these two groups showed statistically significant differences compared with all the other groups ($p<0.05$).

Discussion

The dental pulp is greatly susceptible to thermal damage and increases in pulp microcirculation temperature during operative procedures. This in turn leads to inflammatory reactions and consequent damage to pulp tissue [4]. Several factors can affect increase in pulp chamber temperature such as cavity preparation, bleaching of teeth, laser applications, polishing of dental materials, composition of dental materials, remaining dentin thickness, distance between the LCU and material surface, position of the LCU, exposure time, and light intensity of the LCU. Polymerization-induced temperature increase depends on two main factors; heat generated by the LCU and exothermic polymerization of the material [16-18].

Effects of external heat application on pulp tissues have been investigated in many studies [4,15,16,19]. In the present study, we aimed to determine effects of different pulp-capping liners and LCU devices on increase of pulp chamber temperature in primary and permanent teeth.

Pediatric dentistry clinics perform restorative treatments of both primary and permanent teeth. Primary teeth have different composition than permanent teeth, and clear definition of the effect of dental materials on pulp tissue is important. Therefore, we used both primary and permanent teeth in this study.

Pulp microcirculation plays an important role in regulation of intrapulpal temperature changes when pulp tissue is affected by thermal stimuli [18]. In the presence of thermal factors, pulpal neurons are stimulated and blood circulation in the pulp chamber is increased, whereby heat distribution occurs. In teeth lacking in the microcirculation mechanism, larger increases in intrapulpal temperature have been demonstrated [12,20]. In most *in vitro* studies, treated teeth are placed in a water tank containing standing water at 37 ºC with the aim of mimicking mouth temperature. In order to simulate circulation of the pulp chamber, we used a pulpal-blood microcirculation apparatus reported by Sari et al. [21] as reference. Remaining dentin thickness plays an important role against harmful thermal stimuli. An inverse ratio between dentin thickness and temperature increase is known [22,23]. We set remaining dentin thickness at 1 mm to simulate deep caries cavities.

An in vitro study on rhesus monkeys by Zach and Cohen [4] reported that a 5.5 ºC temperature increase in the pulp chamber caused irreversible pulpitis in 15 % teeth, and 11.2 ºC and 16.6 ºC increase caused necrosis in 60 % and 100 % teeth, respectively. Studies have determined that 42 ºC is a critical temperature at which a sustained exposure for one-minute causes irreversible pulpitis in pulp tissue [24,25].

All materials tested in our study were observed to experience temperature increase below the critical value (42 ºC) under both light sources (3M Elipar or VALO LED) in both primary and permanent teeth pulp chambers. The lowest temperature rise was observed in the ACTIVA-BioACTIVE (respectively; 2,15±0,29-1,78±0,34- 3,08±0,42-2,36±0,74) compared with all the other pulp-capping materials. A probable reason for this is difference in composition among the materials. While all other materials contain calcium hydroxide and calcium silicate filler, ACTIVA-BioACTIVE contains a BioACTIVE resin matrix and BioACTIVE fillers. Heat capacity is related to thermal conductivity of materials and materials with low heat capacity show high thermal insulation properties [26]. One of the most important effects of liners is thermal insulation, indicating the effect of material composition. Thermal conductivities of organic materials are generally lower than those of inorganic materials [27]. Based on the results obtained in this study, ACTIVA-BioACTIVE has lower heat capacity than other pulp-capping materials.

Light intensity of light curing units is an important factor in pulp chamber temperature change during dental material polymerization [28]. Several manufacturers have recently introduced light curing units with irradiance approaching 1000mW/cm^2 to reduce clinical working time and increase depth of polymerization degree. LED LCUs, which are more widely used than other light sources, have many advantages such as low heat generation, resistance to overheating, long life, and minimized light output over time [29].

Savaş et al. [19] evaluated temperature changes in the pulp chamber during polymerization of four different pulp-capping materials using an LED-light-curing-unit (VALO LED), and during polymerization of each pulp-capping material, temperature increase in the pulp chamber was found to be between 1.06 ºC and 2.43 ºC. They reported that use of the VALO LED did not cause a temperature increase above the critical value (42 ºC) in the pulp chamber. Yazıcı et al. [5] evaluated the temperature increase in a pulp chamber due to use of various light-curing units during resin composite polymerization, and they reported the highest intrapulpal temperature with the Halogen LCU (3.8 ºC), followed by the Plasma Arc (2.4 ºC) and LED (2.1 ºC) LCUs.

In the present study, two different light curing units with radiation values approaching 1000 mW / cm^2 were evaluated. Under both light sources, temperature increase in the pulp chamber of primary and permanent teeth using all pulp-capping materials was observed to be below the critical value. Temperature increases in the pulp chamber were between 1.78 ºC and 3.07 ºC in the VALO LED groups and between 2.36 ºC and 3.82 ºC in the 3M-Elipar LED groups. Temperature increases in the pulp chamber under the VALO LED LCU were found to be less than those under the 3M-Elipar LED LCU, and the differences were statistically significant. Therefore, we infer that the VALO LED LCU glass lens enhances the ability to focus and collimate light intensity, resulting in minimally decreased power density [19].

In this study, temperature increase in the pulp chamber of primary teeth was more than that in the pulp chamber of permanent teeth, under both light sources and using all pulp-capping materials. In agreement with our results, Kahveci et al. [28] found that increase in pulp chamber temperature of primary teeth was more than that of permanent teeth. Studies have reported physical, chemical, and morphological differences in dentin structure between primary teeth and permanent teeth. The number of dentin tubules in primary teeth is lesser and their peritubular dentin is two to five times thicker and approximately 10 times wider compared with permanent teeth [30,31]. Based on the results of our study, it can be hypothesized that temperature increases are dependent on these structural differences.

Conclusions

Within the limitations of this study, the following conclusions can be drawn:

- Differences in compositions of pulp-capping materials affect temperature increase in the pulp chamber. The ACTIVA BioACTIVE Base/Liner, showing low temperature increases during polymerization in the pulp chamber, might be preferable as an indirect pulp-capping material in deep cavities.
- VALO LED may be preferred in especially deep cavities in dental restorative procedures because it causes less temperature increase in pulp chambers. Further, because compliance in pediatric procedures may decrease during long treatment sessions, use of VALO LED may help shorten treatment times.

- In addition, in cases treated under general anesthesia, VALO LED can be used to reduce duration of treatment.

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All authors have made substantive contribution to this study and/or manuscript, and all have reviewed the final paper prior to its submission. The authors declare that they have no competing interests.

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Figure Legends

Fig. 1. Mechanism of the measurement of intrapulpal temperature changes.

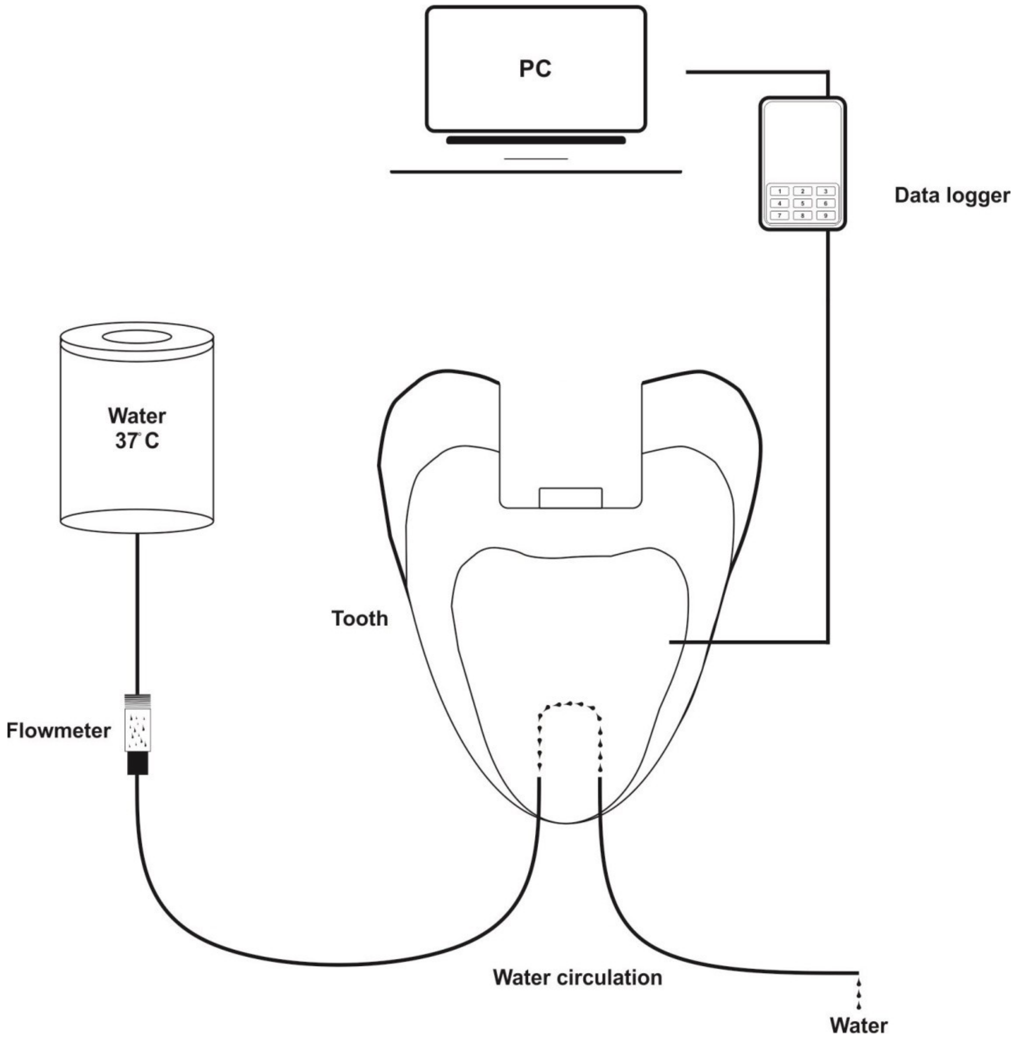

Fig. 2. Group design.

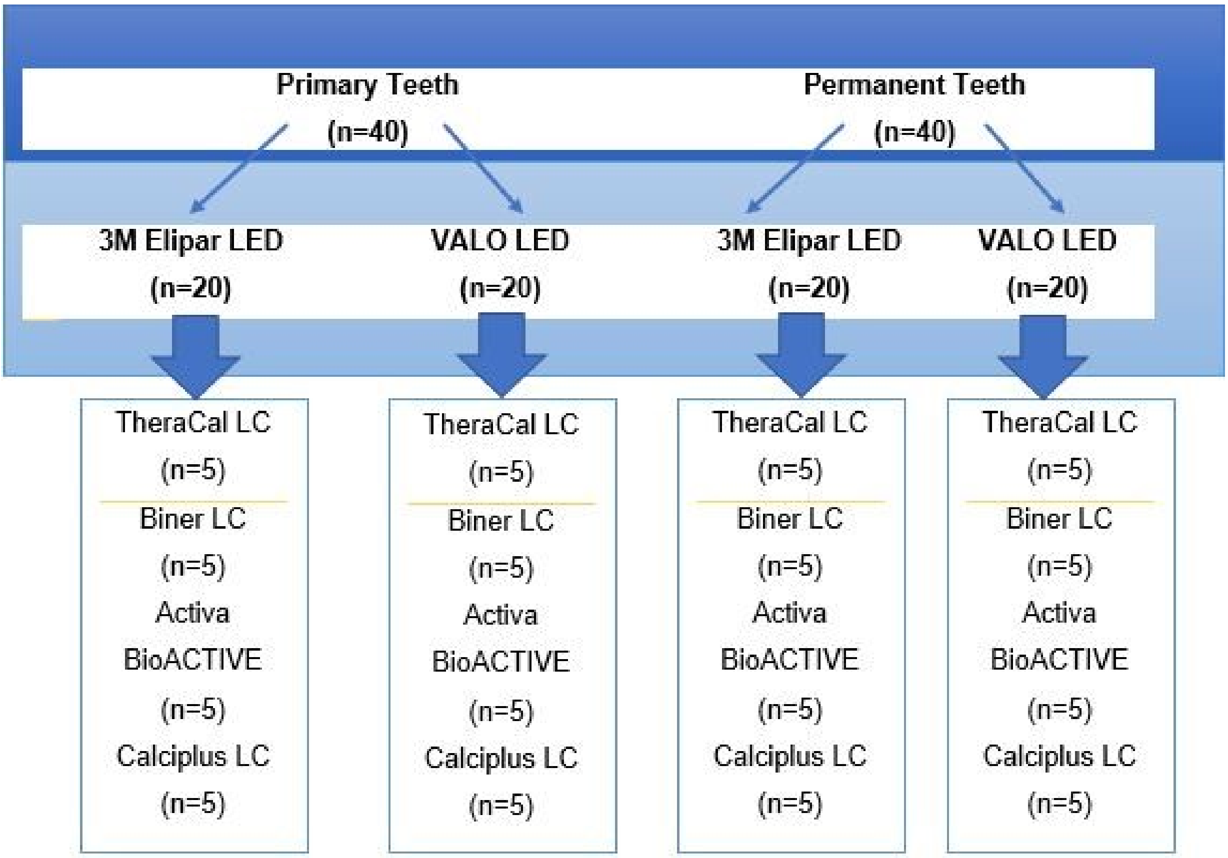

Table 1. Restorative Materials.

Material Type	Commercial Name	Manufacturer	Composition
Light curing resin-modified calcium silicate	TheraCal LC	Bisco Inc, Schamburg, IL, USA	Aerosol 8.0%, biocompatible hydrophilic resin 42.5% (Bis-GMA 20%, biocompatible resin-FDA 77.25%, modifying agent 2.4%; initiating agent 0.32%, stabilizer for the initiating agent 0.032%), active ingredients in MTA 44.5%, and barium sulfate 5%
Light curing calcium hydroxyphosphate	Biner LC	Meta Bıomed Inc, Horsham, PA	Diurethane dimethacrylate, Hydroxyapatite, Triethyleneglycol dimethacrylate, Aerosol, Barium aluminium borosilicate
Light curing BioACTIVE resin matrix	ACTIVA BioACTIVE Base/Liner	Pulpdent Corp. Watertown, USA	Blend of diurethane and other methacrylates with modified polyacrylic acid (44.6%), Amorphous silica (6.7%), Sodium fluoride (0.75%)
Light curing calcium hydroxyphosphate	Calciplus LC	Imicryl Inc. Konya, Turkey	Resin Matrix: Urethane Dimethacrylate, ULS monomer (Ultra Low Syhrinkage Monomer), Photoinitiator, Stabilizors. Filler: Ultra Fine Bioactive glass, fluoroaluminasilicate glass, antibacterial nano composite filler.

Table 2. Light Curing Units

Commercial Name	Manufacturer	Power Intensity, Exposure Time
VALO LED	Ultradent Products Inc., South Jordan, USA	4500 mW/cm^2, 3 s
3M Elipar LED	3M, ESPE, St.Paul, MN, USA	1000 mW/cm^2, 20 s

Table 3. The mean and standard deviations of the temperature rise for all groups.

Pulp capping materials	**VALO LED**		**3M Elipar LED**	
	Primary teeth	Permanent teeth	Primary teeth	Permanent teeth
TheraCal LC	2,85±0,32^{a}	2,27±0,57^{a}	3,36±0,47$^{a, b}$	2,94±0,61^{a}
Biner LC	3,07±0,32^{a}	2,68±0,78^{a}	3,82±0,58^{a}	3.24±0,43^{b}
Activa-BioACTIVE	2,15±0,29^{b}	1,78±0,34^{b}	3,08±0,42^{b}	2,36±0,74^{c}
Calciplus LC	2,25±0,37^{b}	1,81±0,62^{b}	3,21±0,52$^{a, b}$	2,47±0,46^{c}

*The letters sign statistically different groups (p<0.05)

Table 5. T test values of light curing units for tooth groups.

	VALO LED					**3M Elipar LED**				
	N	**Mean**	**Std. Error Mean**	**Test Value**	**Sig. (p)**	**N**	**Mean**	**Std. Error Mean**	**Test Value**	**Sig. (p)**
Primary teeth	20	2,5855	,09270	3,684	**,001<0,05**	20	3,3675	,06779	5,718	**,000<0,05**
Permanent teeth	20	2,1150	,08783			20	2,7525	,08351		
Total	40	2,3503	,07343			40	3,0600	,07240	-6,883	**,000<0,05**